Silvicultural Prescription
For
The Flight 93 National Memorial,
Somerset County, Pennsylvania

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Prepared for
National Park Service
Flight 93 National Memorial

June, 2013

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Introduction

On August 29-31, 2012 personnel from the USDA Forest Service, Northeastern Area, Forest Health Protection, Morgantown, WV. Field Office conducted a survey to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae* Annand (Hemiptera: Adelgidae), population densities at the Flight 93 National Memorial in southwestern Pennsylvania. The purpose of the survey was to assess the need for treatment in the hemlock grove area of the crash site. Hemlock woolly adelgid is present throughout the survey areas at high levels. A biological evaluation was prepared in August, 2012 which recommended that a comprehensive hemlock management plan be developed and a chemical suppression/prevention treatment plan be put into place to protect eastern hemlock trees. The release of predatory beetles is also recommended as a potential long-term biological control strategy of HWA.

On May 9, 2013 personnel from the USDA Forest Service (Allegheny National Forest, Northern Research Station, and Northeastern Area, Forest Health Protection, Morgantown, WV. Field Office) visited the hemlock grove at the Flight 93 crash site to evaluate overall stand stocking and condition, and assess silvicultural needs for the stand. A silvicultural prescription was prepared in June, 2013 as part of a comprehensive hemlock management plan for the hemlock grove. This prescription includes guidelines for designation of trees to receive chemical HWA suppression treatment to meet short and long-term desired vegetation conditions for the site.

Project Location/Description

The Flight 93 National Memorial is located in southwestern Pennsylvania in Somerset county (40º04'N, -78º53'W). The Memorial covers approximately 2,200 acres of which 1,025 acres are forested (figure 1). The Memorial lies in the Appalachian mixed hardwood region (Rhoads and Block, 2005) within the oak-hickory ecological forest type, which is associated with oaks (*Quercus*) yellow popular (*Liriodendron tulipifera* L.) and northern hardwood forest cover type (Smith et al. 1983). The site has been extensively modified by human activity related to the mining of bituminous coal (USDI, 2007). The elevation of the site is 2,360 feet above sea level.

The crash site is located within a fenced area (fenced in 2001) near the southern end of the memorial, and contains a number of building and structures (USDI, 2007). This area covers 38 acres of which 18 acres are forested (figure 2.). The hemlock grove is enclosed within the fenced area and covers 11 acres (figure 3). Soils within the forested area of the crash site are classified as Atkins, Brinkerton and Cavode silt loams (NRCS, 2012). These soils are moderately to poorly drained with similar topographic relief (<3% slope) and shallow water table (<18 inches; (NRCS, 2012).

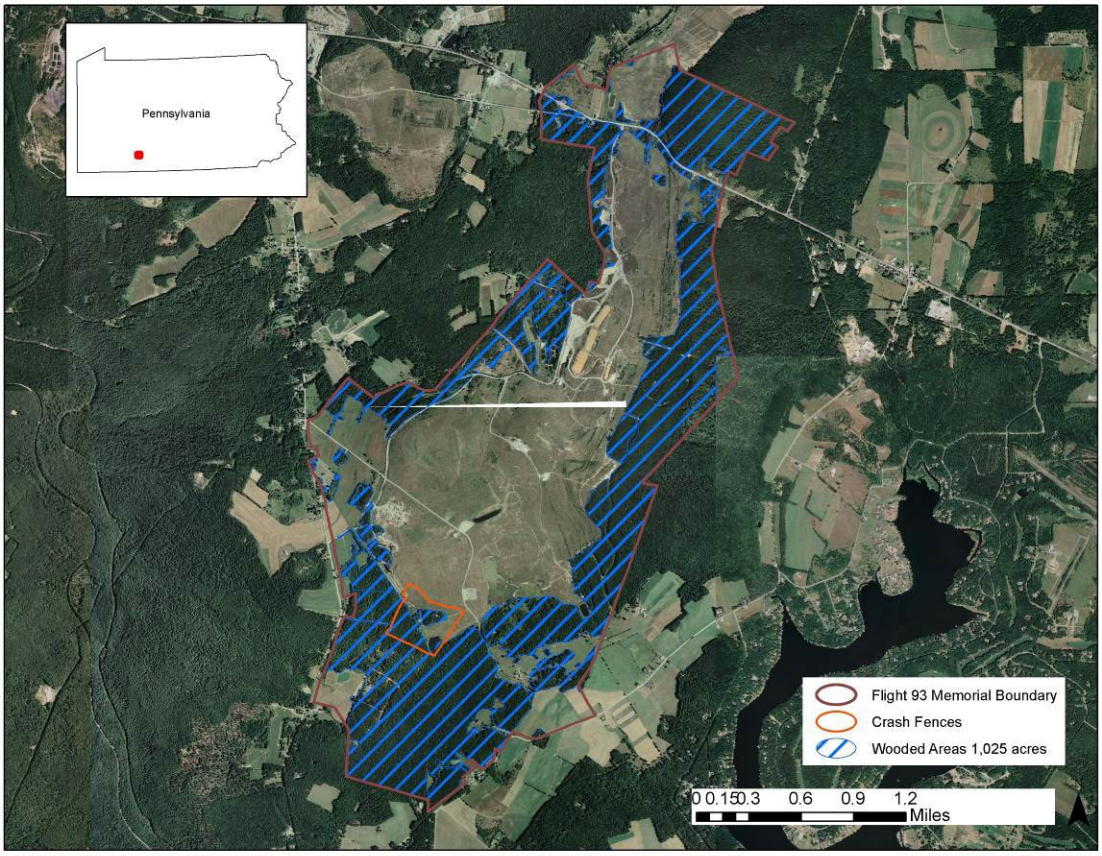

Figure 1. Flight 93 National Memorial, Somerset County, Pennsylvania.

Stand Delineation and Inventory Methods

ARCMAP data

We used ARCMAP® data provide by U.S. Department of the Interior, National Park Service to identify the administrative boundary area and crash site (Callahan, 2012). These boundary areas were then overlaid with National Agricultural Imagery Program (NAIP) data and Google earth imagery, which was used to digitize tree cover, calculate acreage, and select survey points (figure 3).

Figure 2. Flight 93 National Memorial crash site, Somerset County, Pennsylvania.

Inventory plots and monitoring trees

To inventory and assess HWA populations we established ten, 1/20th acre (26.3 ft. radius) fixed radius overstory plots within the hemlock grove (figure 3). Plot locations were randomly selected using ARCMAP and monumented with wooden stakes. Tree and sapling data were collected on all trees at least 1.0 inches in diameter at breast height (dbh; 4.5 ft. above the ground; USDA 2001) within each 1/20 th acre plot. For each tree (≥ 5.0 inches dbh) we recorded species, crown class (i.e. dominant, co-dominant, intermediate, and overtopped; USDA 2001), and dbh. For all saplings (≥ 1 inch but < 5 inches dbh) we recorded species, and dbh. We assessed seedlings (0.5 ft. tall to < 1 in. dbh) on a nested 1/500th-acre (5.2 ft. radius) fixed radius microplot within each overstory plot. On each microplot we recorded species, size class, and tallied the number of seedlings present. Presence of HWA and other insect pests was noted throughout the stand during this survey. At each plot location five overstory eastern hemlock trees (50 total) were randomly selected for visual evaluation and monitoring. For each of these trees we recorded dieback (none, light 1-15 %, moderate 16-30 %, heavy >30 %), and crown transparency (< 30 %, 31-50 %, >50 %; USDA 1999).

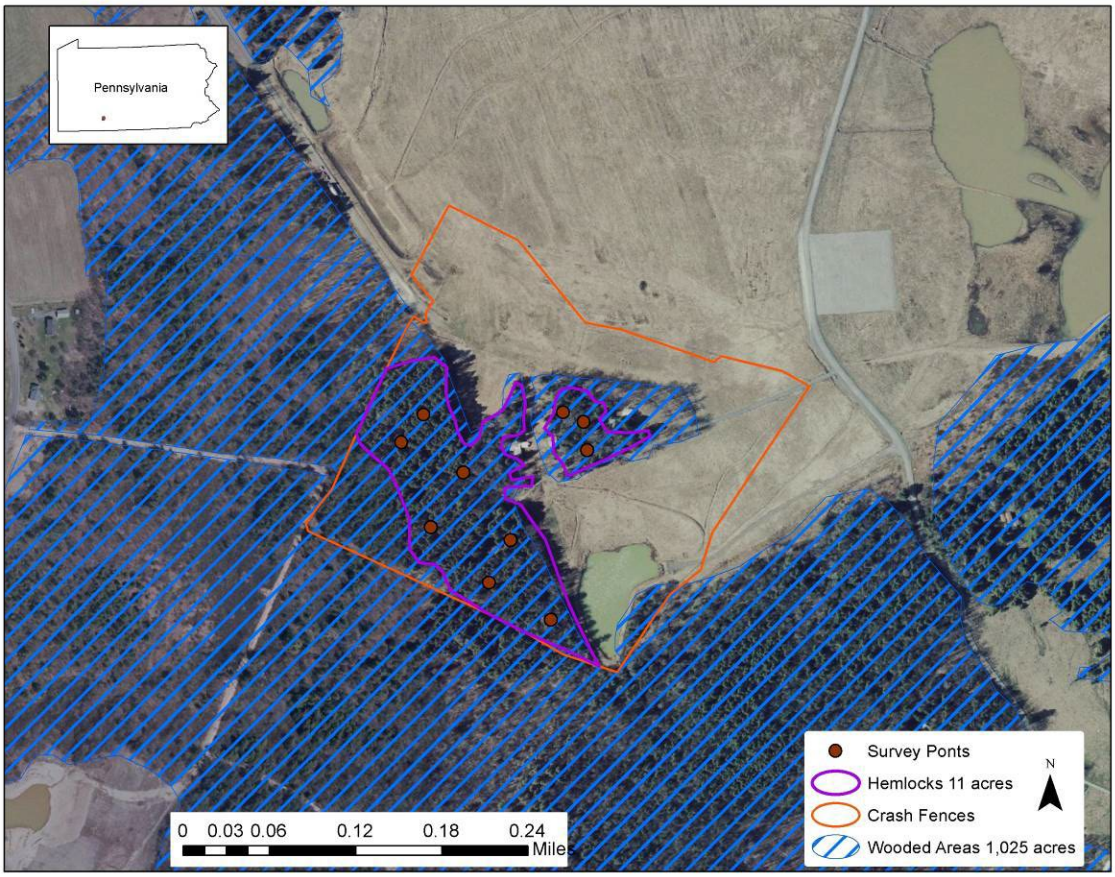

Figure 3. Hemlock grove and survey plot locations, Flight 93 National Memorial, Somerset County, Pennsylvania.

Data analysis
Data were entered to the SILVAH software program (version 6.2, July 2012), in order to generate stand tables by basal area, relative density, and trees per acre.

Stand Condition

Species composition, basal area and stocking
This 11-acre stand is dominated by eastern hemlock, and total basal area including living and standing dead trees is 258.6 ft²/acre with a stem density of 388 trees per acre and a QSD of 11.1 inches. The average living basal area is 235.8 ft²/acre with a stem density of 314 TPA and a QSD of 11.7 inches (table 1).

Eastern hemlock accounts for an average of 151.6 ft²/acre of live basal area with a density of 222 TPA and a QSD of 11.2 (table 1). Other species account for an additional 84.2 ft²/acre of live basal area with a density of 92 TPA and a QSD of 13.0 inches, represented in decreasing order of abundance (trees per acre) by red maple (*Acer rubrum*), black cherry (*Prunus serotina)*, black birch (*Betula lenta*), northern red oak (*Quercus rubra*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*). Black cherry is the most abundant hardwood in terms of basal

area, and northern red oak is the largest diameter hardwood measured. Also observed in the stand, though not reflected in plot data are scattered eastern white pine (*Pinus strobus*) and American beech (*Fagus grandifolia*). Shrub species present included rosebud rhododendron (*Rhododendron maximum*), greenbrier (*Smilax sp*.) and poison ivy (toxicodendron radicans). Herbaceous species such as fern and sedges (Carex spp.) were also observed.

Trees larger than 6 inches in diameter are dominated by eastern hemlock, while the sapling layer consists of eastern hemlocks, red maple, black birch and yellow birch. Eastern hemlocks also dominate the sapling layer. Evidence of past harvesting activity was observed in the stand.

Table 1. Existing Stand Conditions: Basal area per acre, trees per acre and quadratic stand diameter (QSD), live and dead stems, for hardwoods, hemlock, and all sampled species.

	Live			Dead			Live and Dead		
Species	**BA/Ac**	**TPA**	**QSD**	**BA/Ac**	**TPA**	**QSD**	**BA/Ac**	**TPA**	**QSD**
Hardwoods	84.2	92	13.0	0.2	2	4.0	84.4	94	12.8
Hemlock	151.6	222	11.2	22.6	72	7.6	174.2	294	10.4
All Species	235.8	314	11.7	22.8	74	7.5	258.6	388	11.1

With a live basal area per acre of 235.8 ft²/ acre, 314 trees per acre, a QSD of 11.7 inches and mean stand diameter of 16.7 inches in trees that are pole-sized and larger, the stand is well above the optimal stocking level for an even aged hemlock stand (figure 4). In an overstocked hemlock stand, early branch pruning occurs, tree crowns narrow and condense, growth slows (Godman and Lancaster 1990) and self-thinning (mortality) occurs. Even though eastern hemlock is considered one of the most shade tolerant of all tree species (Godman and Lancaster 1990) stands that contain over 200 ft^2 of basal area are considered heavily stocked (Lancaster, 1985). At these high densities tree mortality exceeds growth so net stand growth becomes negative.

Seedling Densities

There is an average of 1,525 stems per acre of regeneration (< 0.5 feet tall; table 2). Red maple was found in four of the 10 plots and accounted for the majority of established regeneration with a total of 5,450 stems per acre (<0.5 feet tall). Eastern hemlock had the next highest regeneration rate in the under 0.5 foot tall size class with a total of 400 stems per acre. There is also a small component of sugar maple and black cherry in the under 0.5 foot tall size class (table 2). In the 0.5-1 foot tall size class eastern hemlock and red maple are equally represented (300 stems per acre), followed by green ash (*Fraxinus pennsylvanica;* 100 stems per acre) and black cherry (50 stems per acre). In the 1-3 feet size class green ash represented the largest component with 400 stems per acre. In this class, red and sugar maple were equally represented with 150 stems per acre followed by eastern hemlock (100 stems per acre) and Cucumber magnolia (*Magnolia acuminate*) and northern red oak with 50 stems per acre each. The only species tallied in the 3-5 feet size class was green ash (50 stems per acre; table 2).

Sapling densities

There is an average of 29 saplings per acre (1-4.4 inches dbh; table 2). The majority of those saplings are eastern hemlock (70 stems per acre), followed by black birch (14 stems per acre) and red maple (two stems per acre).

Table 2. Seedling/sapling summary for the hemlock grove, Flight 93 National Memorial, Somerset County, Pennsylvania.

	Stems per Acre/Size Class							
Species	**<0.5 feet**	**0.5-1 feet tall**	**1-3 feet**	**3-5 feet**	**>5'-<10 feet**	**>10ft<1in**	**1-4.4 inch**	**Total**
Eastern Hemlock	400	300	100	0	0	0	70	870
Red Maple	5,450	300	150	0	0	0	2	5,902
Sugar Maple	150	0	150	0	0	0	0	300
Green Ash	0	100	400	50	0	0	0	550
Cucumber Magnolia	0	0	50	0	0	0	0	50
Red Oak	0	0	50	0	0	0	0	50
Black Cherry	100	50	0	0	0	0	0	150
Black Birch	0	0	0	0	0	0	14	14
Total stems per acre	**6,100**	**750**	**900**	**50**	**0**	**0**	**86**	**7,886**

Insect activity data

Hemlock woolly adelgid is present in the stand and its distribution is patchy across the hemlock grove. Hemlock woolly adelgid was observed in three of the 10 overstory plots surveyed, and in 12 of the 50 monitoring trees. No other hemlock pests were observed (e.g. scale insects, mites). Unfortunately, it is often difficult to determine if tall overstory hemlock trees have been effected by HWA because their branches are simply too high to see, even with the use of binoculars. Thirty-four percent of the eastern hemlock trees that could be surveyed were infested with HWA and 18.5 % of the overstory trees inventoried were dead eastern hemlocks. HWA was observed in 5.43 % of the codominant trees and 23.1 % of the suppressed trees.

Of the 50 eastern hemlock monitoring trees surveyed, 90 % are experiencing some level of dieback. Two percent are showing a high level of dieback, 16 % have a medium level of dieback, 72 % are showing a light level of dieback and 10 % have no dieback. Ninety-six percent of the monitoring trees had <30 % transparency, the other four percent had 31-51 % transparency.

The eastern hemlock trees present in the grove grow very slowly because the stand is currently well above the recommended stocking level. The crowded conditions impose limitations on the amount of light, water and nutrients available to each tree. The presence of HWA in the stand

creates additional stress on the eastern hemlock trees within the stand. Heavy to moderate dieback was observed in 20 % of the monitoring trees and four percent of the trees are showing a moderate level of transparency. This reduction in crown is likely the result of a combination of the crowded conditions and feeding by HWA. The presence of HWA in the hemlock grove raises concerns about the long-term stability and viability of eastern hemlock at the memorial.

Mortality

Eight out of the 10 overstory plots surveyed had standing dead eastern hemlocks, and 25% of all eastern hemlocks surveyed were dead, predominantly those in the suppressed crown positions. Total standing dead basal area in the hemlock grove was 22.9 ft^2/acre, with a stem density of 74 TPA and an average diameter of 7.5 inches. Eastern hemlock mortality represented 8.7 % of the total basal area and over 99 % of the TPA of standing dead. We attributed the current hemlock tree mortality primarily to overstocking and not yet to HWA feeding.

Long Term Stand Management Objectives

Long term vegetation management objectives emphasize retaining the hemlock grove as a key component of the Memorial. This 11 acre hemlock stand is highlighted on interpretive signs and maps as "the hemlock grove", and it is the focal point for visitors to the Wall of Names and Memorial Plaza. The stand was permanently altered by the impact of the plane. The hemlocks in this grove are integrated into the memorial site design- a ceremonial gate by the Wall of Names is built from hemlock. It is desirable to maintain the "wall of hemlock" behind the impact site into perpetuity. In order to maintain the long-term desired vegetation condition of sustaining eastern hemlock at the Flight 93 Memorial site, it is recommended that additional treatments occur to provide for recruitment of healthy eastern hemlock and other conifer that will contribute towards diversity of the site. Part of a long term strategy for management of the site should also maintain hardwoods as a component of the stand, while reducing hardwood encroachment along the eastern portion or 'wall of hemlock' portion of the stand.

Due to the uncertainty associated with future eastern hemlock mortality and potential for other invasive species and climate change to affect this hemlock grove in the long term, it is recommended that an adaptive management approach be utilized. This includes sustaining some hardwoods in the stand for diversity, providing for hemlock recruitment over time, and promoting species suited for warmer, drier climates such as eastern white pine (either planted or natural regeneration that does become established).

Short Term Stand Management Objectives

Short term stand management should be directed towards reducing stand stocking and improving health of desired eastern hemlocks.

Because the stand is overstocked, self-thinning is occurring via individual stem mortality; additional mortality is anticipated from HWA infestation in the immediate future. Action should

be taken through selective application of pesticides for HWA control, combined with predatory beetles, to maintain sufficient numbers of eastern hemlock to achieve B-level stocking (see figure 4). Trees that are not treated with pesticides and beetles will die from HWA infestation and crowded conditions, resulting in a gradual thinning of stand to B-level stocking. If no action is taken, near complete mortality of eastern hemlock at the site can be expected from HWA infestation.

A fully stocked even-aged eastern hemlock stand with a QSD of 16.7 inches should have between 80 and 90 trees per acre and a BA/Ac of 140-150 ft²/acre for optimum health and growth (figure 4) (Lancaster, 1985).

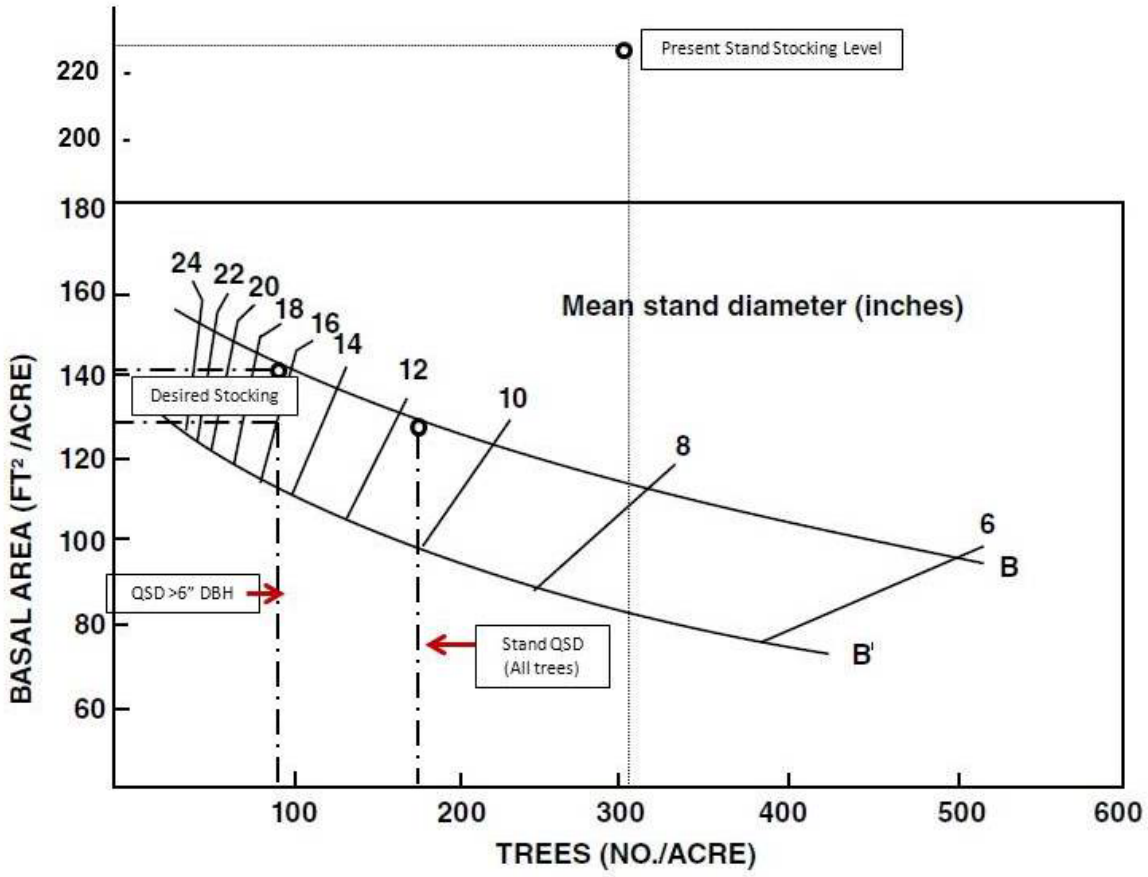

Figure 4. Residual stocking levels (B and B' levels) for even-aged hemlock stands based on number of trees, mean stand diameter, and basal area per acre. B level represents minimum residual stocking of stands with 30 % or more hemlock initially. B' level applies to stands with 15 - 29 % hemlock. (In mixed stands, the percentage of hemlock is based on a comparison of hardwood stems in the main crown canopy and the hemlock six inches DBH and larger in the overstory and understory positions (Lancaster, 1985).

Stand Prescription, Marking and Treatment Guidelines

Integrated Pest Management
Currently, the only available options for protecting eastern hemlock from HWA are individual tree chemical treatments. Treatments are limited by the biology and feeding behavior of HWA, its population densities, the site conditions (i.e. proximity to streams), accessibility and the limited application technology currently available. Insecticide treatments are effective, although they are conducted on an individual tree basis and can be both labor intensive and costly. Thus treatment strategies are typically focused in high value sites such as recreational or scenic areas, including important national parks such as the Flight 93 Memorial. Classical biological controls such as predators and pathogens are being pursued by the USDA Forest Service but will likely take years to become effectively established. As such, preservation of eastern hemlocks at the grove will require intensive monitoring and an aggressive chemical treatment strategy.

Chemical treatment of selected understory and overstory eastern hemlock trees at recommended stocking levels and the release of biological control agents is recommended based on the following considerations.

1) The hemlock grove is currently overstocked. Trees will continue to die as a result of competition. Reducing the TPA and density will increase the overall health of the stand and allow for selection of the best growing stock and promote the sustainability of the hemlock stand.

2) Chemical treatments are recommended for HWA control on individual eastern hemlock trees in the hemlock grove. Insecticides have been shown to be an effective treatment against the hemlock woolly adelgid and will allow for the retention of eastern hemlock within the grove.

3) Release and establishment of *Sasajiscymnus tsugae, Scymnus sinuanodulus,* and *Laricobius nigrinus* predatory beetles is also recommended in infested areas on eastern hemlocks that are not in close proximity to chemical treatments. The establishment of these natural enemies offers the opportunity for long-term control and may minimize the need for repeated chemical treatments in future years.

Marking Guidelines
Designate 140-160 ft^2/acre, or 80-100 trees per acre of the best quality co-dominant and dominant eastern hemlocks to be chemically treated for HWA. Select eastern hemlock in a co-dominant or dominant position, with new growth visible, and those with seedling and sapling regeneration beneath them. Soil injection and/or horticultural oils may be applied where seedling and sapling eastern hemlock regeneration occurs, to reduce HWA infestation on understory trees. Mark additional trees along the eastern and northern edges (100’ in) of the stand, along the opening, to maintain windfirmness and dense hemlock visible from the Memorial Plaza. Also

mark additional eastern hemlock along the southern boundary of the 3 acres eastern piece of stand to potentially provide for wind-firmness of this portion of the stand (see figure 5).

Once initial rounds of insecticide treatments are completed, designate additional hemlock in the sapling classes for recruitment into larger size classes over time, particularly along the eastern edges of the grove, facing Memorial Plaza. Likewise, consider treating areas with more abundant hemlock seedling and small sapling regeneration with horticultural oils or soil drenches to provide for hemlock recruitment.

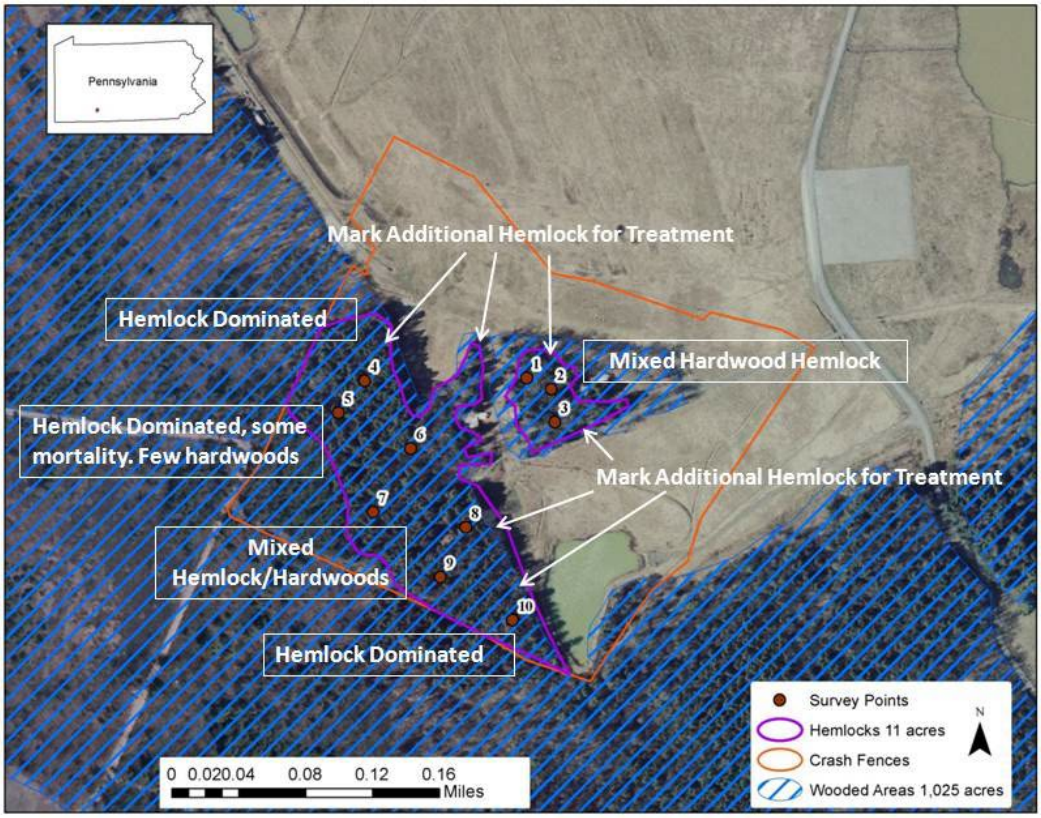

Figure 5. Hemlock grove marking notes, Flight 93 National Memorial, Somerset County, Pennsylvania.

Treatment of HWA

Treat the marked trees using systemic insecticides, consistent with insecticide labels. HWA populations appeared most abundant along the eastern portions of the stand facing the Memorial Plaza, and these hemlocks appeared to have the least amount of healthy new growth. Treat these portions of the grove first, particularly if pesticide label limitations will constrain the number of stems that can be treated in a given year. Combine pesticide applications with release of predatory beetles and other biological controls to manage HWA populations, as controls becomes available, based on best available science.

Systemic Insecticides

Several systemic insecticides labeled for adelgids can be injected (e.g. imidacloprid, dicrotophos), implanted (e.g. acephate) or sprayed on the bark (e.g. dinotefuran) or foliage of eastern hemlock trees. Imidacloprid is by far the most common systemic insecticide being used to control HWA and is applied as a soil drench, truck injection, foliar treatment or soil application. These insecticides are absorbed and trans-located by the vascular system of the tree to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, Evans 2000, Steward and Horner 1994, McClure 1992).

Biological Controls

There are no known parasites of adelgids. There are three predatory beetles that have been released againist the HWA: *Sasajiscymnus tsugae* (Sasaji & McClure: Coleoptera: Coccinelidae), Scymnus sinuanodulus (Yu & Yao; Coleoptera: Coccinelidae) and *Laricobius nigrinus* Fender (Coleoptera: Derodontidae). Each with its own unique dispersal habits, reproductive potential, feeding behavior, and suitable climate regimes. They are all fairly host specific. Releases are usually done in infested hemlock stands found along the leading edge, or in areas where hemlocks are still healthy and HWA densities have not yet overwhelmed the trees. The release and establishment of HWA natural enemies is not likely to provide any short term control of HWA. This long-term approach is still experimental and will likely require a complex of natural enemies to maintain HWA below damaging levels. It may be years before these predators can self-perpetuate sufficiently before any level of success can be determined.

Treatment of interfering vegetation

Rhyzomous ferns were abundant in the northern portion of the grove. It may be necessary to reduce the abundance of the fern through selective herbicide applications. Products containing sulfometuron methyl (e.g. Oust®) have been shown to be quite effective in reducing abundance of herbaceous interfering vegetation such as ferns, while allowing existing tree seedlings to persist in treated areas (Horsley 1981, 1988, 1991).

Removal of dead trees

Falling woody debris from dead trees within the grove will present a threat to visiting family members. Dead trees should be felled to maintain scenic integrity of the site and reduce hazards to family members and staff in the hemlock grove. In order to reduce secondary insect pests from infesting the stand, the following guidelines should be followed:

- Fell trees between September and January if possible.
- Avoid piling slash next to standing residual trees.
- Cut stem material down to pieces no more than 8 feet long to promote rapid decay of material.
- Cut tree tops down to within 1’ of ground to promote rapid decay and maintain scenic integrity of site.

Conifer Planting

Underplanting of occasional eastern white pine (native species observed in the stand), combined with treatments to recruit existing eastern hemlock seedling regeneration along the northern and eastern edges (50' into stand) of the grove will maintain 'wall of hemlock' appearance, enhance species diversity, and provide for eventual recruitment of eastern hemlock into the overstory at the site. Underplanting of eastern white pine along the southern and western edges, 50 feet inside and outside the treeline of the hemlock grove would provide for eventual growth of additional coniferous species along the windward edges of the grove, potentially enhancing windfirmness of the site in the long-term (see figure 6)

Where HWA mortality causes overstory stocking to fall below 110 ft²/acre (~50% stocking), consider underplanting with eastern white pine and possibly some eastern hemlock if they can be protected via soil injections of insecticides until landscape level, longer term controls for HWA become available.

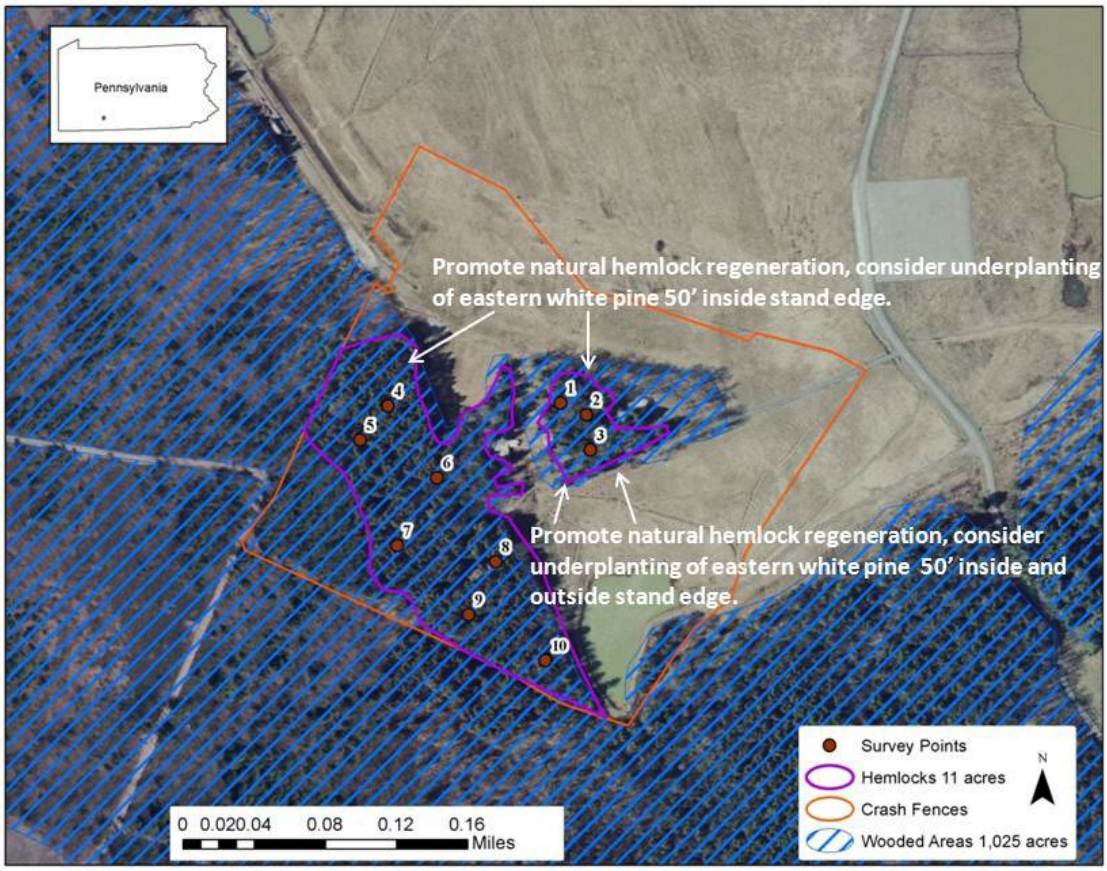

Figure 6. Hemlock grove and recommended underplanting areas, Flight 93 National Memorial, Somerset County, Pennsylvania.

Treatment of Hardwoods at site

Hardwoods are invading portions of the edge of the hemlock grove facing the Memorial Walkway. Remove most of the hardwoods to favor eastern hemlocks and maintain the 'wall of

hemlock' visible from the walkway. This will require the planting of eastern hemlock along the edge of the hemlock grove facing the Memorial. Retain a few better quality hardwoods for diversity, as a hardwood seed source, and to lend additional structural support to the hemlock grove (e.g. protection from environmental stressors). All other hardwoods and non-native invasive plants such as multi-flora rose within crash impact area should be removed to maintain herbaceous vegetation on site.

The majority of the seedlings and saplings on the site are green ash, red maple, birch and other hardwood species. The more shade intermediate of these species such as red maple and birch will persist within canopy gaps and along the edges of the stand where more sunlight reaches the forest floor. Allow these seedlings and saplings to naturally fill into canopy gaps as they occur over time, in order to sustain a small hardwood component of various ages in the stand.

Treatment of Additional Eastern hemlock
Consider developing a similar long-term strategy for management of the eastern hemlock southeast of the hemlock grove, outside the perimeter fence, but visible from the Memorial Plaza.

References

Doccola, J.J., P.M. Wild, I. Ramasamy, P. Castillo, and C. Taylor. 2003. Efficacy of arborjet viper microinjections in the management of hemlock woolly adelgid. Journal of Arboriculture. 29(6): 327-330.

Evans, R.A. 2000. Draft Environmental Assessment: for the Release and Establishment of *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a Biological Control Agent for Hemlock Woolly Adelgid (*Adelges tsugae*) at the Delaware Water Gap National Recreation Area. USDI, National Park Service, Northeastern Region. 23 p.

Godman, R.M. and K. Lancaster. 1990. *Tsuga canadensis* (l.) Carr., eastern hemlock. In: R.M. Burns and B.H. Honkala, eds. Silvics of North America, vol.1, conifers. USDA Forest Service, Agriculture Handbook No. 654. pp. 604-612.

Horsley SB. 1981. Control of Herbaceous Weeds in Allegheny Hardwood Forests with Herbicides. Weed Science 29:655-62.

Horsley SB. 1988. Control of Understory Vegetation in Allegheny Hardwood Stands with Oust. Northern Journal of Applied Forestry 5(4):261-2.

Horsley SB. 1991. Using Roundup and Oust to control interfering understories in Allegheny hardwood stands. McCormick LH, Gottschalk KW. Central Hardwood For. Conf., General Technical Report NE-148. University Park, PA. Radnor, PA: USDA Forest Service.

Lancaster, K. F. (1985). *Managing Eastern Hemlock a Preliminary Guide.* Northeastern Area: U.S.D.A Forest Service.

McClure, M.S. 1992. Effects of implanted and injected pesticide and fertilizers on the survival of Adelges tsugae (Homoptera: Adelgidae) and on the growth of Tsuga canadensis. Journal Econ. Entomol. 85(2) 468-472.

NRCS. 2012. Natural Resources Conservation Service (NRCS) Soil Survey. http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm (accessed August 16, 2012)

Rhoads A.F. and T.A. Block. 2005. Trees of Pennsylvania: A Complete Reference Guide. Philadelphia, PA: University of Pennsylvania Press.

Smith, H.C., Della-Bianca L., and H. Fleming. 1983. Silvicultural systems for the major forest types of the United States. In: Agricultural Service Handbook 445. Washington, D.C. 141-156.

Steward, V.B., and T. A. Horner. 1994. Control of hemlock woolly adelgid using soil injections of systemic insecticides. J. Arboric. 20(1): 287-288.

USDI. United States Department of the Interior. 2007. Flight 93 National Memorial Final General Management Plan/Environmental Impact Statement. Washington, DC.

Webb, R.E., J.R. Frank, and M. J. Raupp. 2003. Eastern hemlock recovery form hemlock woolly adelgid damage following Imidacloprid therapy. Journal of Arboriculture. 29(5): 298-302.